Improving Digital Halftones by Exploiting Visual System Properties

Jeffrey B. Mulligan

NASA Ames Research Center, MS 262-2, Moffett Field CA 94035-1000

1. Abstract

The visibility of quantization noise in digital halftones can be predicted from psychological data on spatial and temporal contrast sensitivity. Simple models of the visual system can be incorporated into halftoning algorithms to minimize the visibility of the resulting artifacts. Filter-based algorithms may be customized to match the error filter to human contrast sensitivity under known viewing conditions. The relative insensitivity of the visual system to high frequency chromatic modulation allows visible luminance noise to be reduced at the expense of additional (but invisible!) chromatic noise. The techniques are easily extended to three dimensions for displays which can be modulated in time such as CRT's and flat panel displays.

2. Introduction

The problem of representing continuous tone images on a binary display device is known as "halftoning" or "dithering" (a good survey can be found in Ulichney [1]). Halftoning works because the human visual system integrates information over spatial regions, so that a spatial pattern of light and dark can evoke a sensation approximating that of a uniform gray area even when the individual display elements can be resolved. When the observer is far away, or the display device has extremely high resolution, the dithered version may be indistinguishable from the original. In many cases, however, the dithered image *will* be distinguishable from the original. The *quantization noise* is the difference image formed by subtracting the original image from the dithered image. The goal of visually-optimized halftoning is to make the quantization noise as invisible as possible while maximizing the visual fidelity of the encoded image.

In this paper we will consider how existing dithering algorithms can be improved and/or tuned to particular viewing situations by the application of knowledge of parameters of the human visual system. Three important variables which are important to the visual system are space, time, and color. Knowledge of spatial sensitivity to visual patterns allows us to tune algorithms for optimal performance at a particular viewing distance. On dynamically controllable devices such as CRT's and flat panel displays, patterning in time can be used to increase gray level resolution and improve perceptual segregation of the signal image and the halftoning noise. When color images are processed, the different parameters describing spatial and temporal sensitivity to chromatic and achromatic image components can be exploited to improve the rendition of the achromatic component by shifting noise to chromatic bands to which observers are less sensitive.

3. Visual System Parameters

3.1. Spatial Sensitivity

The human visual system is not equally sensitive to spatial patterns of different sizes. The *contrast sensitivity function* (CSF) describes the visual response to spatial patterns as a function of spatial frequency [2,3]. The units used to describe spatial frequency depend on which journal one is reading. In the vision literature, spatial